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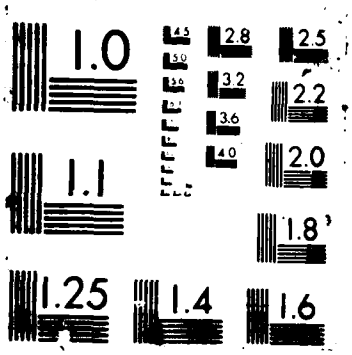
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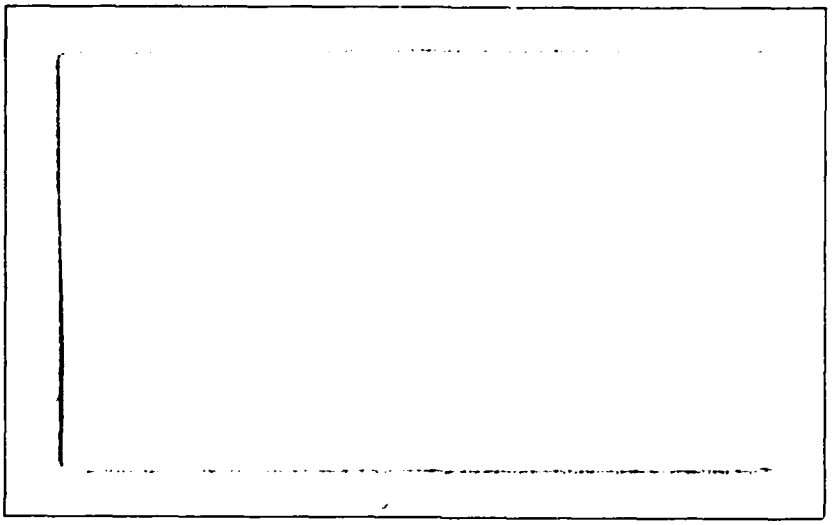

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Applied Research in Statistics - Mathematics - Operations Research

FINAL REPORT

RESEARCH ON STATISTICAL METHODOLOGY APPLICABLE TO TECHNICAL PROBLEMS ASSOCIATED WITH NAVY PROGRAMS

by

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Technical Report No. 123-4

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I. INTRODUCTION

The major goal of the Navy's Ship Auxiliary Machinery Program is to provide improved equipments and procedures for existing and future ships. Meeting this goal requires extensive development and performance evaluation tasks. These tasks are not necessarily straightforward, since improvement is not defined by a single quantity, but rather by a number of interrelated factors such as efficiency, reliability, maintainability, weight, cost, etc. As a result, the development and evaluation phases tend to be relatively complex in nature. These phases generally involve the preparation of test plans tailored to specific experimental requirements and the efficient acquisition, appropriate analysis and proper interpretation of the experimental results

Under Office of Naval Research contract N00014-84-C-0573, Desmatics, Inc. investigated statistical methodology and developed statistical techniques to aid the Navy in reaching the major objective of this program. Desmatics' involvement and accomplishments during the research effort have been documented in a series of 31 informal technical notes distributed to cognizant Navy scientists and engineers. These technical notes address a wide variety of technical problems requiring statistical expertise and assistance.

Three formal technical reports were also prepared under the contract. In addition to being distributed to pertinent Naval personnel, these reports were submitted to the Defense Technical Information Center for general dissemination. One of these technical reports was the basis for an invited journal article in Communications in Statistics. Another report was the basis for an invited presentation at the 1986 Winter Simulation Conference.

II. RESEARCH SUMMARY

During the course of its research effort, Desmatics was involved in a number of Navy experimental programs, primarily at the David Taylor Naval Ship Research and Development Center (DTNSRDC) and at the Naval Research Laboratory (NRL). Within each of these research programs, the participation of Desmatics centered on the development of the most appropriate statistical techniques for the problems being addressed. Because of the nature of these problems, the major portion of the Desmatics research effort was devoted to applied statistical research, primarily involving experimental design, reliability and maintainability, and data analysis topics. Furthermore, because the technical problems being addressed were generally subject-matter dependent, Desmatics staff members worked closely with Navy scientists and engineers. The following sections provide a brief description of two main technical areas in which Desmatics was involved.

A. ANALYSIS OF ORGANOTIN RELEASE RATES OF ANTIFOULING COATING SYSTEMS

The U.S. Navy has become increasingly concerned with the effects of marine bio-fouling on ship performance. The increase in friction and drag which results from marine fouling of a ship's hull can increase fuel consumption by as much as 20%. To control marine bio-fouling on ship hulls, the Navy has traditionally used copper-based antifouling paints on most of its vessels. More recently, however, the Navy has begun to implement the fleetwide use of organotin antifouling paints that contain tributyltin (TBT), a tin-based compound, as a biocide. Organotin antifouling compounds have been

shown to be substantially more effective in controlling marine bio-fouling than copper-based antifouling coatings.

To provide quality assurance and to help in the selection of suitable organotin antifouling coatings, scientists at DTNSRDC are currently conducting a research program to develop analytical standards for organotins and to evaluate various proposed methods for TBT-release rate assessment. Desmatics' involvement with this program has been devoted to providing technical and analytical support on various related statistical aspects.

The TBT-release rate of a paint is determined by placing a coated specimen panel or cylinder into a container of synthetic seawater, measuring the increasing concentration of TBT in the water, and plotting it against time. Samples are extracted at various times after placing the specimen in the water, and a number of replicate measurements (i.e., subsamples) are made of each sample. Desmatics developed two alternative statistical models to describe this sampling and measurement process, and derived the appropriate methodology for estimating the TBT-release rate of a paint, as well as constructing associated confidence intervals for this rate.

Using these statistical models, Desmatics compared the efficiency of various proposed sampling schemes. In fact, given the costs of extracting and analyzing samples and subsamples, optimal sampling procedures were developed by Desmatics. Additional analyses performed by Desmatics included:

(i) estimation of the within-specimen and between-specimen variation for test panels (or cylinders) coated with the same antifouling paint;

(ii) determination of the reliability of the measurement process;

(iii) investigation of the effects of temperature, pH, and time on TBT-release rates,

and (iv) examination of relative error and error propagation in the measurement of TBT-release rates.

B. DEVELOPMENT OF RELIABILITY AND MAINTAINABILITY TEST PLANS

Scientists in the DTNSRDC Ship Auxiliary Machinery Program are continually developing and testing new equipment for Navy use. Desmatics developed reliability and maintainability test plans for several types of equipment, including a trash compactor for use on Navy submarines, a shipboard trash compactor, some vacuum-flush fixtures from competing manufacturers, and a steam disinfection unit.

For the trash compactor evaluations, there were severe time constraints on the reliability tests. Accordingly, Desmatics provided sequential test plans which enabled the experimenters to reach conclusions in the minimum possible amount of time. The maintainability tests were based on simulated failures and large sample sizes were possible if necessary. Desmatics prepared tables showing the probability of demonstrating the required mean time to repair (MTTR) as a function of the true MTTR and sample size. Additional tables gave the factors needed to construct tolerance limits for the upper percentiles of the repair time distributions.

For the vacuum-flush fixtures, several units of each type were available for testing. Under the assumption of an exponential failure time distribution, which was thought to be reasonable, failure data from different units could be easily combined. This alleviated the severe constraints on the reliability tests, and it was thought best to use fixed sample size tests. Power curves were prepared giving the probability of demonstrating the

required mean time between failures (MTBF) as a function of the true MTBF and sample size. In addition, procedures were given for obtaining confidence intervals for the ratio of MTBFs from different manufacturers.

The steam disinfection unit was designed for thermal treatment of shipboard-generated sewage. The effluent was required to contain less than a specified fecal coliform concentration at least a certain percentage of the time. Desmatics prepared a set of binomial acceptance sampling plans and a table which provided the necessary information for choosing the most suitable plan subject to time and resource constraints. This table showed the largest success rate which could be demonstrated with 95% confidence as a function of sample size and the observed number of failures.

III. TECHNICAL REPORTS

As previously mentioned, the research conducted by Desmatics under Contract No. N00014-84-C-0573 has been documented in 31 informal technical notes and in three formal technical reports. The three technical reports and their corresponding abstracts are listed in this section.

Desmatics Technical Report Number: 123-1 Date: May 1986

Title: AN EVALUATION OF PROPOSED SAMPLING PROCEDURES FOR DETERMINING ORGANOTIN RELEASE RATES

Abstract: Scientists at the David Taylor Naval Ship Research and Development Center are currently developing and evaluating a new procedure for measuring the release rate of organotin from antifouling paint. As part of this procedure, a panel painted with organotin antifouling paint is placed in a test tank filled with water. The release rate of organotin is determined by measuring the increasing concentration in the water, and plotting it against time. The slope of this line as determined by linear regression provides an estimate of the organotin release rates.

The objectives of this technical report are to:

(1) develop a statistical model which describes the sampling procedure,

(2) present a method for estimating the release rate and obtaining corresponding confidence intervals,

(3) discuss the optimum number of subsamples which should be made and the optimum sampling times,

(4) compare the current procedure against several different procedures which have been proposed.

Desmatics Technical Report Number: 123-2 Date: October 1986

Title: EFFICIENT IDENTIFICATION OF IMPORTANT FACTORS IN LARGE SCALE SIMULATIONS

Abstract: Large, complex computer simulation models can require prohibitively costly and time-consuming experimental programs to study their behavior. Therefore we may want to concentrate the analysis on the set of "most important" factors (i.e., input variables). Factor screening experiments, which attempt to identify the more important variables, can be extremely useful in the study of such models. The number of computer runs available for screening, however, is usually severely limited. In fact, the number of factors often exceeds the number of available runs. In this paper we present a survey of supersaturated designs for use in factor screening experiments. The designs considered are: random balance, systematic supersaturated, group screening, modified group screening, T-optimal, R-optimal, and search designs. We discuss in general terms the basic technique, advantages, and disadvantages of each procedure surveyed.

Note: This technical report was the basis for an invited presentation at the 1986 Winter Simulation Conference.

Desmatics Technical Report Number: 123-3 Date: January 1987

Title: GROUP TESTING WITH TEST ERROR AS A FUNCTION OF CONCENTRATION

Abstract: A common assumption in group testing applications is that there is no test error, i.e., misclassification of a single item or a group of items cannot occur. Graff and Roeloffs (1972) have proposed a procedure applicable when there is a known probability of misclassification. We generalize their results to the situation where the probability of misclassification depends on the proportion of defective items in the group.

Note: This technical report was the basis for an invited journal article to be published in Communications in Statistics.

IV. TECHNICAL NOTES

In addition to the technical reports listed in the previous section, Desmatics prepared 31 technical notes which were submitted to cognizant Navy scientists and engineers. These technical notes communicated statistical design plans, data analysis results, and recommendations. The following pages provide a listing of their titles.

Technical Note No.	Date	Title
123-1	1 Oct 84	RECOMMENDATIONS FOR EVALUATION OF SUBMARINE TRASH COMPACTOR UNIT
123-2	16 Oct 84	FURTHER ANALYSIS OF ORGANOTIN RELEASE RATES
123-3	22 Oct 84	STATISTICAL ANALYSIS OF OCM COMPARISON EXPERIMENT
123-4	1 Nov 84	REANALYSIS OF pH EFFECT ON ORGANOTIN LEACH RATES
123-5	27 Nov 84	RECOMMENDATIONS FOR EVALUATION OF SHIPBOARD VERTICAL TRASH COMPACTOR
123-6	12 Dec 84	FURTHER RECOMMENDATIONS FOR EVALUATION OF SHIPBOARD VERTICAL TRASH COMPACTOR
	28 Dec 84	APPENDIX TO TECHNICAL NOTE NO. 123-3
123-7	28 Dec 84	RECOMMENDATIONS FOR EVALUATING THE RELIABILITY OF VACUUM-FLUSH FIXTURES
123-8	30 Jan 85	A STATISTICAL ANALYSIS OF THE RELIABILITY OF THREE LUBRICANTS
123-9	1 Apr 85	AN APPROACH FOR FITTING A CUBIC*EXPONENTIAL DECAY REGRESSION FUNCTION
123-10	14 Nov 85	A STATISTICAL ANALYSIS OF DATA FROM THE SMALL CRAFT AND BOAT OILY BILGE WATER SAMPLING PROGRAM
123-11	2 Dec 85	BINOMIAL ACCEPTANCE SAMPLING PLANS FOR LABORATORY EVALUATION OF A STEAM DISINFECTION SYSTEM
123-12	18 Feb 86	ANALYSIS OF DATA FROM THE SMALL CRAFT OIL-WATER SEPARATOR PROGRAM
123-13	8 May 86	A STATISTICAL ANALYSIS OF DATA FROM NAVY CABLE FIRE EXPERIMENTS: CONTINUITY TESTS
123-14	12 Jun 86	STATISTICAL CONSIDERATIONS IN THE DESIGN OF NAVY CABLE FIRE EXPERIMENTS
123-15	19 Jun 86	STATISTICAL SAMPLING PLANS FOR SHIPBOARD EVALUATION OF A STEAM DISINFECTION SYSTEM

Technical Note No.	Date	Title
123-16	26 Jun 86	A DISCUSSION OF STATISTICAL ANALYSIS TECHNIQUES FOR A CORROSION TEST LOOP EXPERIMENT
123-17	30 Jul 86	ANALYSIS AND DISCUSSION OF SOME PRELIMINARY ORGANOTIN RELEASE-RATE EXPERIMENTS
PV Memo	26 Nov 86	EVALUATION OF FACE SEAL MATERIALS FOR PV LIMITS, WEAR, AND SHOCK RESISTANCE
123-18	Feb 87	STATISTICAL ANALYSIS OF AN EXPERIMENT FOR EVALUATING CREVICE CORROSION IN CHLORINATED SEAWATER
123-19	18 Mar 87	ANALYSIS OF ORGANOTIN RELEASE RATES FROM CYLINDRICAL SPECIMENS AND COMPARISON TO EARLIER PANEL TESTS
123-20	23 Mar 87	ANALYSIS OF A SET OF FAILURE DATA
123-21	4 Jun 87	RECOMMENDATIONS FOR EVALUATING MERCURY REMOVAL CARTRIDGES AND CHLORIDE TESTING PROBES
123-22	9 Jun 87	ANALYSIS AND DISCUSSION OF BEARING LUBRICANT EVALUATION TESTS
123-23	16 Jun 87	ANALYSIS OF ORGANOTIN RELEASE RATES AND COMPARISON OF DIFFERENT PAINT FORMULATIONS
123-24	18 Jun 87	DETERMINATION OF SAMPLE SIZE REQUIRED FOR DEMONSTRATING THE EFFECT OF A SURFACTANT ON TRASH SLUG SINKABILITY
123-25	23 Jun 87	FURTHER ANALYSIS OF A SPECIFIC ORGANOTIN PAINT FORMULATION
123-26	2 Jul 87	STATISTICAL EVALUATION OF THE DESIGN OF TWO CREVICE CORROSION EXPERIMENTS
	6 Jul 87	UPDATE TO TECHNICAL NOTE NO. 123-23
123-27	9 Jul 87	A LOOK AT THE BIOSPHERICS OCM TECHEVAL DATA
123-28	13 Jul 87	STATISTICAL CONSIDERATIONS IN DESIGNING THE BILGEWATER CHARACTERIZATION AND GENERATION SURVEY

Technical Note No.	Date	Title
123-29	20 Jul 87	COMPARISON OF ORIGINAL AND MODIFIED VERSIONS OF TWO ORGANOTIN PAINT FORMULATIONS
123-30	29 Jul 87	AN EXAMINATION OF THE SHIMADZU OCM TEST DATA
123-31	12 Aug 87	STATISTICAL ANALYSIS OF BUTYLTIN CONCENTRATIONS IN SAMPLES FROM THE BACK CREEK-SEVERN RIVER AREA AND RECOMMENDATIONS FOR FUTURE MONITORING

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This final technical report prepared under Contract No. N00014-84-C-0573 summarizes a research investigation conducted by Desmatics, Inc. under sponsorship of the Office of Naval Research. The Desmatics research effort investigated statistical methodology and developed statistical techniques to aid the Navy in reaching the major goal of the Navy's Ship Auxiliary Machinery Program. That goal is to provide improved equipments and procedures for existing and future ships.

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